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Oceanographic Studies on Project Skijump II

By

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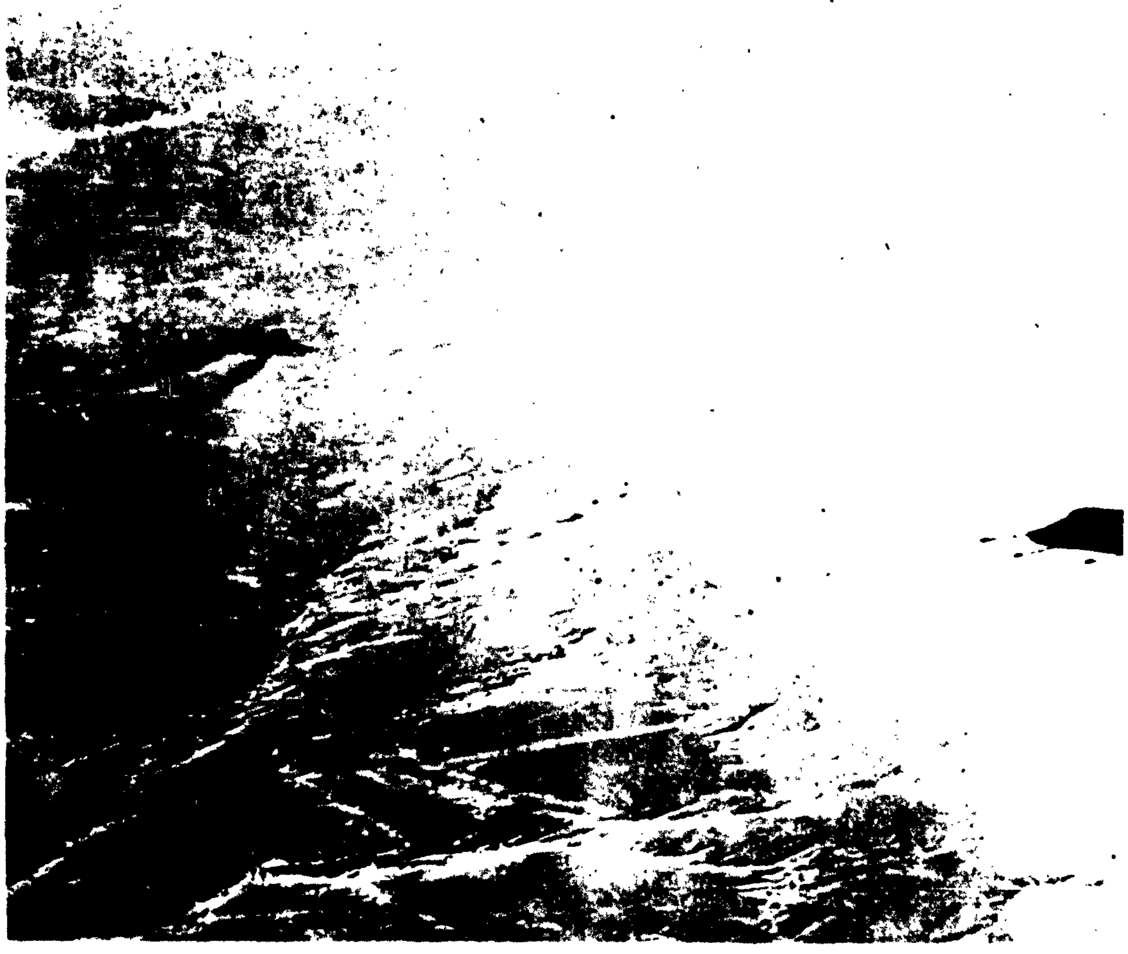
Director

SKIJUMP II



R4D Landing on the Polar Sea

Introduction

The practicability of making oceanographic observations from aircraft in the Polar Sea was demonstrated by Project Skijump I in the early spring of 1951 (W.H.O.I. Technical Report Ref. No. 51-67, September 1951). During this Project, commanded by LCDR. E. M. Ward, U.S.N., twelve landings were made on the Polar Sea with an R4D. Only three hydrographic stations were made on Skijump I largely on account of communications difficulties; it was necessary to return to the base at Point Barrow, Alaska, whenever radio contact was lost. This curtailed the time spent on the ice. The Project was further limited by the small range of the R4D.

In 1952 Skijump II was activated under the command of CDR. V. J. Coley, U.S.N. In addition to the R4D (piloted as before by CDR. E. M. Ward) there were two P2V aircraft capable of refueling the R4D on the ice and thus extending the range of the survey. The positions of Skijump stations are plotted in Figure 1, (stations 1-3 were made on Skijump I), and it can be seen that they go far toward filling the gaps left by previous expeditions.

Stations 4, 5, and 6 were made on successive days, (11-13 March, 1952) with the R4D remaining on the ice during the nights of 11 and 12 March and a P2V coming out to her from Point Barrow each day.

Station 7 was made on 25 March, the R4D remaining on the ice as before. The following day the R4D and a P2V landed at station 8; the P2V refueled the R4D and returned to Point Barrow. The hydrographic station was made during the night of 26 March. On the morning of 27 March the R4D's port landing gear collapsed in an attempt to take off and she had to be abandoned. This concluded the oceanographic section of Skijump II. With the plane it was necessary to abandon the winch, the Nansen bottles, and other equipment. The best operating month from the point of view of light, ice conditions, and air temperature is April, which was lost on account of this misfortune.

Methods

The equipment and methods used in Project Skijump II differed in many particulars from those used in Skijump I and will therefore be described in some detail.

After a landing site had been selected the R4D landed. Before the engines were turned off the ice thickness was measured roughly with the chain saw. If this proved sufficient the P2V landed alongside and preparations were made for refueling the R4D and making station.

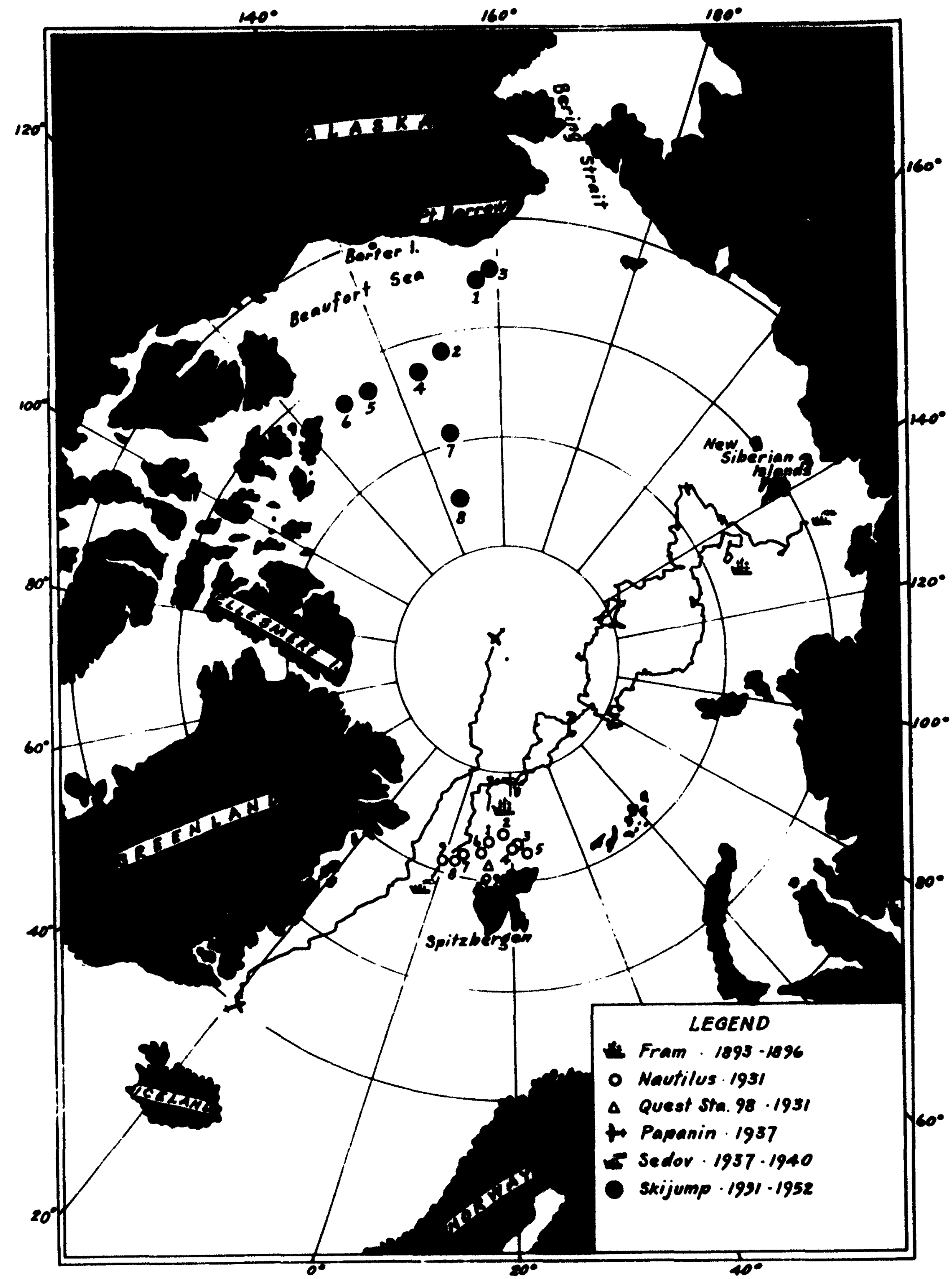


Fig. 1 Expeditions on which oceanographic measurements were made in the deep Polar Basin.

Aboard the R4D the boom was rigged, the meter-wheel attached and a plumb line dropped from the meter-wheel to the ice to determine the position of the center of the hole. The hole was bored with a 5 h.p. McCulloch earth auger with a specially adapted cutting edge. This edge was sharpened and had an angle of 20 degrees from the vertical. The diameter of the hole was 12-1/2 inches which proved sufficient for the passage of Nansen bottles. In Figure 2 drilling has just begun; the meter-wheel can be seen at the top.

After the hole had been drilled a nylon tent was rigged enclosing it with the interior of the plane (Figure 3). The purpose of the tent was to prevent any freezing of the water contained in the Nansen bottles. The plane while on the ice was heated by a gasoline burning space heater; two ducts from this heater entered the plane through one of the ports. The third duct was directed at the top of the hole (Figure 4). The blast of hot air not only kept the hole free from slush ice but kept the temperature in the tent well above freezing.

The winch (Figure 5) was mounted forward. The drum contained 3400 m. of 1/16" stainless steel cable with a breaking strain of 480 pounds. A strip of friction tape was wrapped around the wire before each bottle was attached to adapt the small diameter wire to the clamp on the bottle.

A long rod was run aft from the clutch lever to the observer. This enabled him to control the winch at the critical point when a bottle came to the surface. A station in progress is illustrated in Figure 6.

The after part of the plane where the Nansen bottles were racked was kept as close to 5°C. as possible; enough to preclude freezing but not so much as to necessitate a long wait for the thermometer to come to equilibrium. Comparisons of paired thermometers were made during the last two stations with the following results: (excluding one defective thermometer)

Differences in Corrected Temp. °C.	No. of Observations
.00	7
.01	10
.02	1
.03	1
Total	19

A fifteen pound weight at the end of the wire was found to be sufficient; all wire angles were close to zero. On shallow series the wire was moved up and down by hand for a few seconds to insure proper flushing of the bottles.

Fig. 2 Drilling through the ice.

Fig. 3 The tent - exterior view.

Fig. 4 The tent - interior view. The hot air duct can be seen to the right of the hole. Nansen bottle going down.

Fig. 5 The winch - John Holmes.

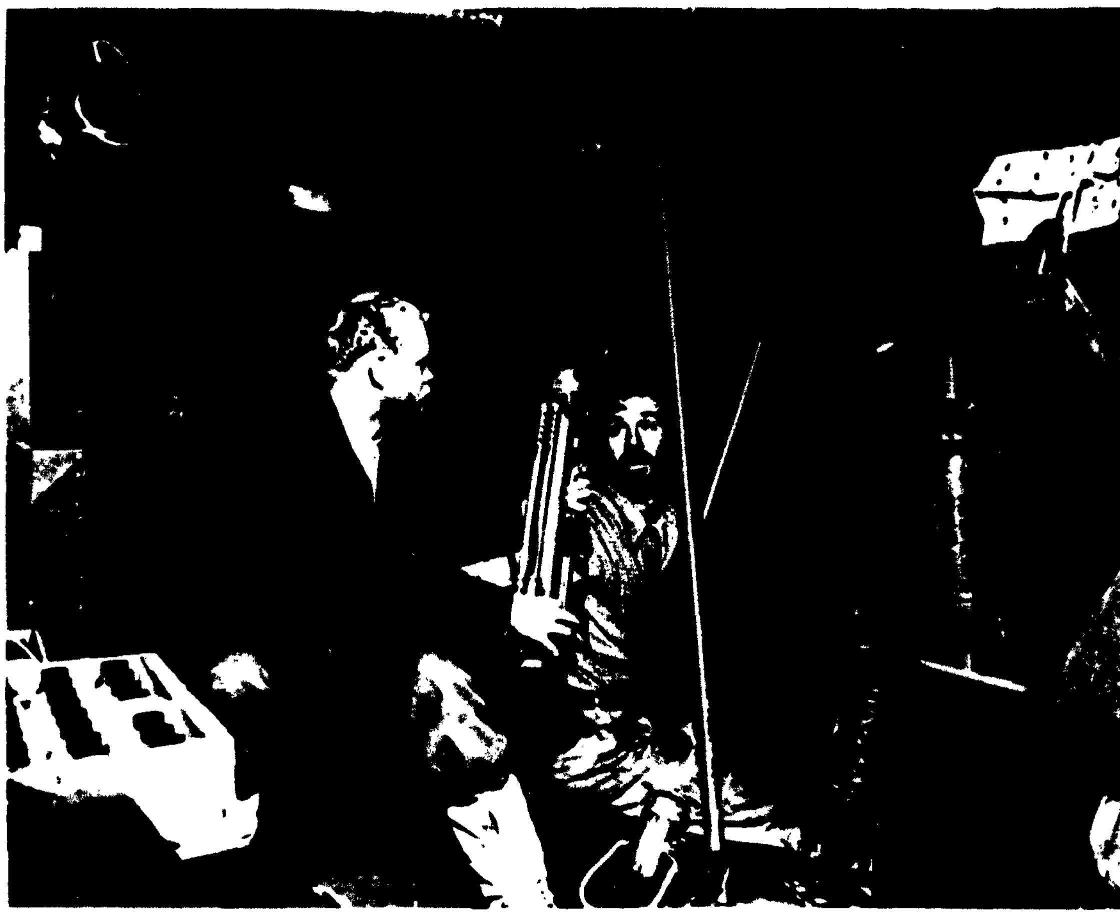


Fig. 6 Working on station - Lt. R. B. Morgan and L. V. Worthington.

The results were somewhat marred by a Nansen bottle which became defective during station 7 and would not close properly. This escaped detection until the samples were analyzed at Woods Hole. There were other cases of pollution that could perhaps have been avoided by a more rigorous testing of Nansen bottles. A tabulation of the hydrographic data can be found at the end (Table I).

Ice Observations

A satisfactory ice runway in the Polar Sea must have the following characteristics: length, smoothness and thickness. These qualifications are best filled by a lead which was frozen in the previous fall or winter and has not been disturbed since by pressure ridges. The length and smoothness of such runways are easily estimated from the air, but the thickness is more difficult to judge. Certain criteria have been found in the course of Skijump I and II which are of some help.

A danger signal indicating thin ice is illustrated in Figure 7. It consists of a more or less regular jigsaw pattern of low ridges. This pattern can be seen in extremely thin ice, (estimated at as little as six inches) which is palpably more transparent than thick ice and thus appears darker in shade. A suggested method by which this pattern may be formed is shown in Figure 8. This pattern was never found when the ice exceeded 3 feet in thickness.

Thick ice is indicated to some extent by the pressure ridges. If the prospective landing spot is surrounded by heavy ridges it is a good sign that the ice is thick. Individual ice cakes which have been upturned are good indicators of minimum ice thickness. A cockpit view of the runway at station 5 is shown in Figure 9. The surrounding ridges are heavy and uninterrupted. The ice at this spot was 5 feet thick.

Unfortunately the distribution of such natural runways is not general throughout the Polar Sea. It is well known that close to shore this ice pack is subjected to greater shear than elsewhere. Thus for a hundred miles or so from Point Barrow pressure ridges tend to form a close network such that large level areas are rarely found. The same thing occurs to the west of Prince Patrick Island where considerable time and gasoline were expended searching for a suitable spot to make station 6.

Of more serious consequence to Skijump II was the lack of good landing places north of about latitude 80°N, for it is to this feature that the loss of the R4D can be in large part ascribed.

Fig. 7 Ice fracture pattern found in thin ice.

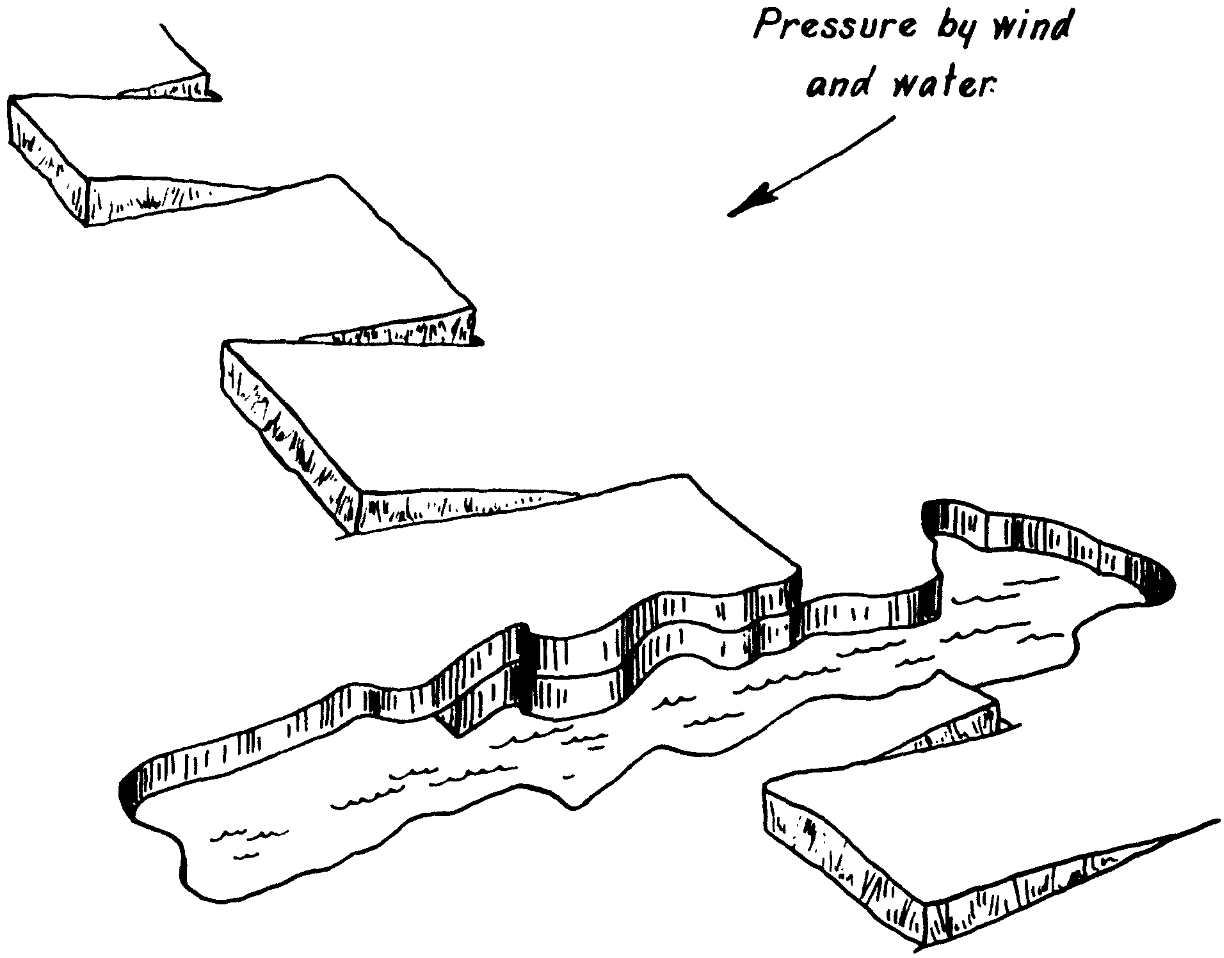


Fig. 8 Thin ice fracture pattern, Section removed to show how fracture took place. The ice sheet closed only the distance of one of the "fingers".

Fig. 9 The runway at Station 5.

In the Beaufort Sea, fair to excellent landing strips were about twenty-five miles apart, but north of 80°N, they disappeared completely. Due to the low supply of gas in the R4D it was necessary to land on old ice, (station 8). It is suggested that since the area in question is in the center of a high pressure cell which is more or less permanent, it is subjected to less violent weather and the ice has less tendency toward opening up.

The appearance of the ice at station 8 is shown in Figure 10. The snow cover averaged two feet deep. The ice beneath the snow cover was very rough, and what appeared to be a snow drift was often found upon examination to be an old weathered down pressure ridge with a snow cover of only six inches. This weathering had resulted in some fine vertical holes which are judged to have been caused by salt cells melting during the summer and boring through the ice cake. The holes which were about 1/4" in diameter were not perpendicular to the axis of the ice cake but truly vertical and evidently drilled by gravity subsequent to the tilting of the ice cake.

Oceanography

Observations in the Polar Sea other than those over the continental shelves are few in number and confined almost entirely to eastern longitudes. It can be appreciated how much can be added to our knowledge of this sea by a very few observations, or even a single observation made in an unexplored area. Only six deep hydrographic stations were made during both Skijump operations but these are sufficient to alter our whole conception of the water circulation in the Polar Sea.

The deep Polar Basin was discovered by Nansen in 1893 in his historic expedition aboard "Fram". (Nansen, 1902). "Fram" was deliberately allowed to be frozen into the ice field, and drifted during the years 1893-1896 from a point north of the New Siberian Islands across the eastern half of the basin to a point north of Spitzbergen where she got free of the ice. During this drift a fund of oceanographic data was provided which has not been equalled by any expedition since.

The submarine "Nautilus" attempted to penetrate the Polar Sea beneath the ice in 1931 (Sverdrup and Soule, 1933). She was prevented from submerging by the loss of a diving plane and was thus limited to a small but most interesting area north of Spitzbergen.

In 1937 a Russian expedition under Papanin landed a plane on the ice close to the pole and drifted, in the course of 274 days, out of the Polar Sea. The expedition was taken off its

Fig. 10 Appearance of last landing field. Crew at work on runway.

ice floe by ship after it has been carried to latitude 71°N by the East Greenland current.

In 1937-1940 the Russian icebreaker "Sedov" roughly paralleled "Fram's" track. Complete published data from the two Russian expeditions are not available but Wüst (1942) was able to piece together some information from various sources including the Russian newspapers. The tracks of these expeditions together with the positions of Skijump's stations are shown in Figure 1. A further expedition in "Maud" (Sverdrup, 1929) attempted to drift across the Polar Sea in 1922. This was certainly the best equipped expedition to set out but by great misfortune "Maud" was unable to penetrate the deep Polar Basin being confined by adverse ice drift to the waters of the Siberian shelf.

What is known of the general character of the Polar Sea has been derived from those expeditions. The surface water is cold (-1.5°C to -1.9°C) and of low salinity (29 ‰ to 33 ‰). This water is formed in the basin itself and is called North Polar water (Nansen, 1902).

Beneath the surface water is a transition layer (of varying thickness) to Atlantic water. This water enters the basin off the west coast of Spitzbergen with temperatures of up to 4° and salinities of slightly more than 35 ‰. A wedge of Atlantic water with temperatures of greater than 0° has been observed at all deep stations in the Polar Sea. The deeper 0° isotherm is found between 700 and 900 m. and provides a convenient lower boundary for this water.

Below the Atlantic water is found the Polar deep water. This water is formed in the Norwegian Sea and consists chiefly of Atlantic water with a slight admixture of North Polar water. As it enters the basin by Spitzbergen it has a slightly lower salinity than the Atlantic water, about 34.94 ‰. Winter conditions in parts of the Norwegian Sea render the whole water column isothermal at temperatures below -1° forming Norwegian Sea deep water which is nearly identical with Polar deep water.

North Polar Water

Nansen considered that the freshness of the North Polar water was maintained by the inflow of fresh water from the great Siberian rivers, and to a lesser extent by the precipitation over the Polar Sea. He based this on salinity values that increased steadily in the surface layers as "Fram" drifted away from the Siberian shelf. It appears from Skijump data that the freshness of the surface layer depends more upon the distance from the source of the saline water than upon the proximity to

the Siberian coast. Skijump stations 4 and 7 had lower salinities (29.34 ‰ and 29.32 ‰) than any of those observed along "Fram's" drift except on the Siberian shelf itself. It is further inferred that any body of sea water subjected to freezing in winter and thawing in summer will develop and maintain its own low salinity surface layer since sea ice has a salinity of only 6 ‰, most of the salt having leached out during the freezing process.

From evidence found in the intermediate layer, station 4 is judged to be in the center of an eddy and is thus farther in point of time from the source of high salinity than any other station yet made in the Polar Sea. In Figure 11 the surface salinities found in Skijump are plotted and the 30 ‰ isohaline sketched in. The higher values are thought to indicate the outer edges of the eddy.

Atlantic Water

As the warmer, more saline water from the Atlantic flows into the Polar Sea it submerges beneath the North Polar water. Progressing further into the basin it gradually cools. The temperature maximum at the entrance near Spitzbergen is above 4° and is found at 50 m. ("Quest" sta. 98, Fig. 1). By "Nautilus" station 5, in the same manner, the maximum is +3.43 at 153 m. The coldest observed maximum +0.32 was found by Nansen at 81°30'N, 125°E at a depth of 400-500 meters. Nansen concluded that the maxima on the Canadian-Alaskan side of the basin would fall below 0° since he considered that the Atlantic water revolved cyclonically around the Polar Sea gradually losing heat.

Skijump maxima ranged from +0.39 to +0.52 at 500 meters. This does not in itself contradict Nansen's theory of the circulation since variations in the maxima have been found in the same locations in different years. For instance, "Fram" station 26 at 84°06'N, 12°26'E shows a maximum of +0.9° while "Sedov" station 39 at 83°59'N, 9°02'E has a maximum of +1.2°. Evidently the temperature of the Atlantic water entering the basin varies from year to year or decade to decade. It is possible that in the years 1893-96 the maxima in the Beaufort Sea were indeed below 0°.

"Fram's" maximum at 84°38'N, 88°00'E in May 1895 was +1.06 at 325 m. while Papanin's maximum near the pole (88°53'N, longitude not given) was +0.74° at 400 m. Both stations are roughly the same distance from Spitzbergen but "Fram's" higher maximum indicates that the warm Atlantic reached her position by a more direct route, especially since the intermediate water has been shown to have been 0.3° warmer in Papanin's day than in Nansen's.

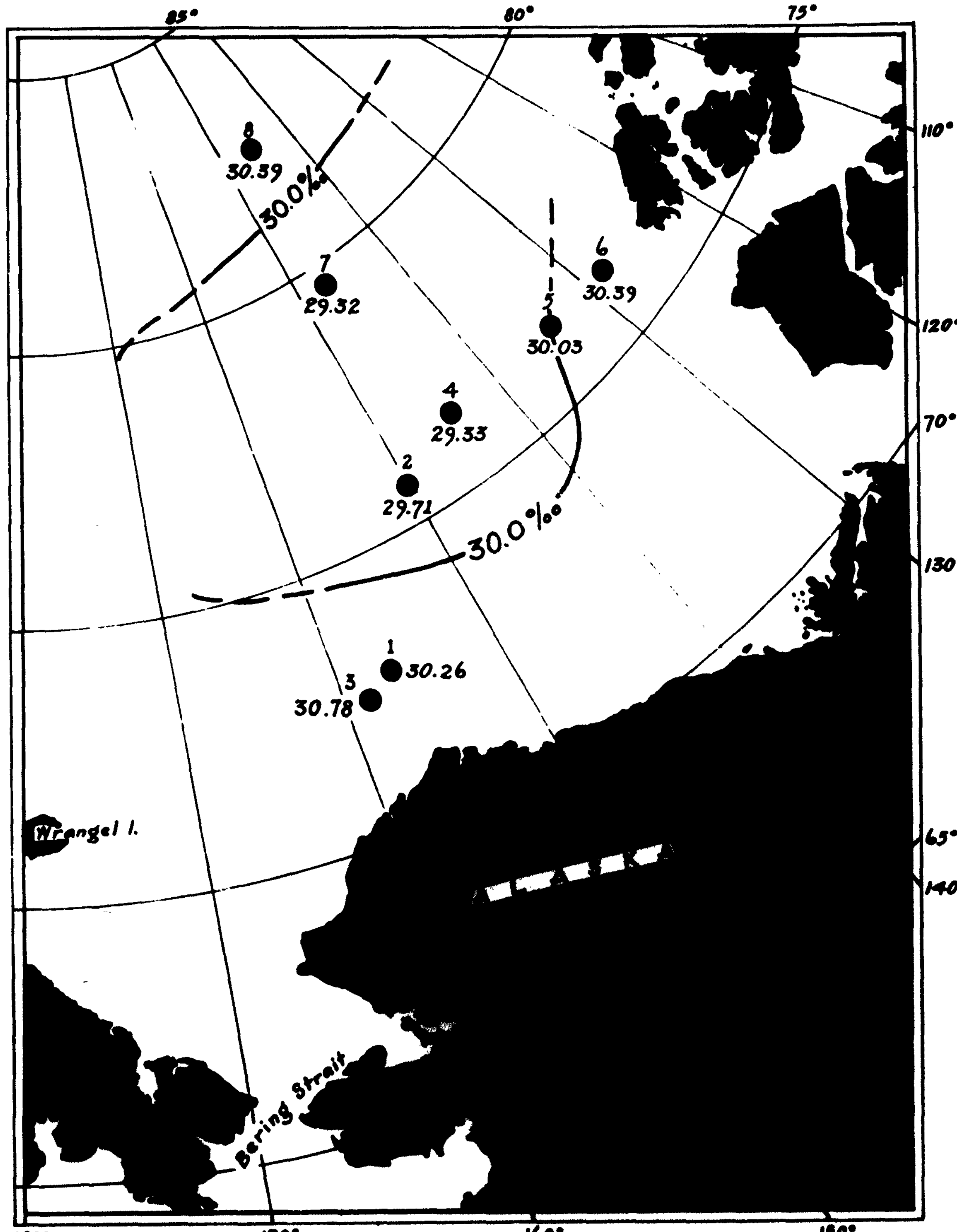


Fig. 11 Salinity $^{0}/_{00}$ of the surface layer. SKIJUMP 1951 - 1952.

On the extreme eastern ends of "Fram's" and "Sedov's" sections, north of the New Siberian Islands, the maximum temperatures start to rise slightly indicating that the warmest water and by inference the strongest current follows the continental slope off the Siberian coast.

A tentative system of Atlantic water circulation in the Polar Sea is illustrated in Figure 12. The major disagreement with Nansen's conception consists in the eddy north of Alaska which was indicated by Skijump data.

The existence of the eddy seems unquestionable in view of the density distribution but there are not enough stations to be sure of its shape. Dynamic computations show transports, relative to the 600 decibar surface, of $3.75 \times 10^6 m^3/sec.$ flowing southward between stations 4 and 6, and $2.66 \times 10^6 m^3/sec.$ flowing eastward between stations 4 and 8. Salinity curves for stations 4, 5 and 6 are plotted in Figure 13. Examination of temperature and salinity data in the Greenland-Spitzbergen channel has failed to show density changes as great as those between stations 4 and 6.

It is difficult to understand what maintains this eddy. Clearly, in the neighborhood of station 4, there is a core of fresh water which has been mixed with Atlantic water to greater depths than elsewhere. The water in this core has a higher specific volume than the water surrounding it and thus horizontal pressure gradients exist. Such pressure gradients according to the circulation theorem are coexistent with currents. Presumably some energy must be supplied to maintain the currents or the gradients, although that energy may be a small fraction of the energy contained at any one time in the currents themselves.

The possibility that this eddy is maintained in part by friction should not be ignored. The source of such frictional energy would be, ultimately, the current entering the Polar Sea by Spitzbergen. A branch of this current, crossing the center of the Polar Basin and turning southward by the Canadian archipelago might supply a small amount of torque. Once an eddy was established the saline Atlantic water might to some extent be excluded from the core, allowing the small addition of fresh water from precipitation to remain in the center.

A further phenomenon observed in Skijump was a small negative thermal gradient found between 50 and 150 m. Two temperature curves showing this conditions are drawn in Figure 14. The gradients appear to be the last remnants of a seasonal thermocline. It is judged that a seasonal thermocline can only have been formed in the Beaufort Sea which was extraordinarily ice-free in the summers of 1950 and 1951. The gradient was most marked on station 7 and least marked on stations 5, 6 and 8.

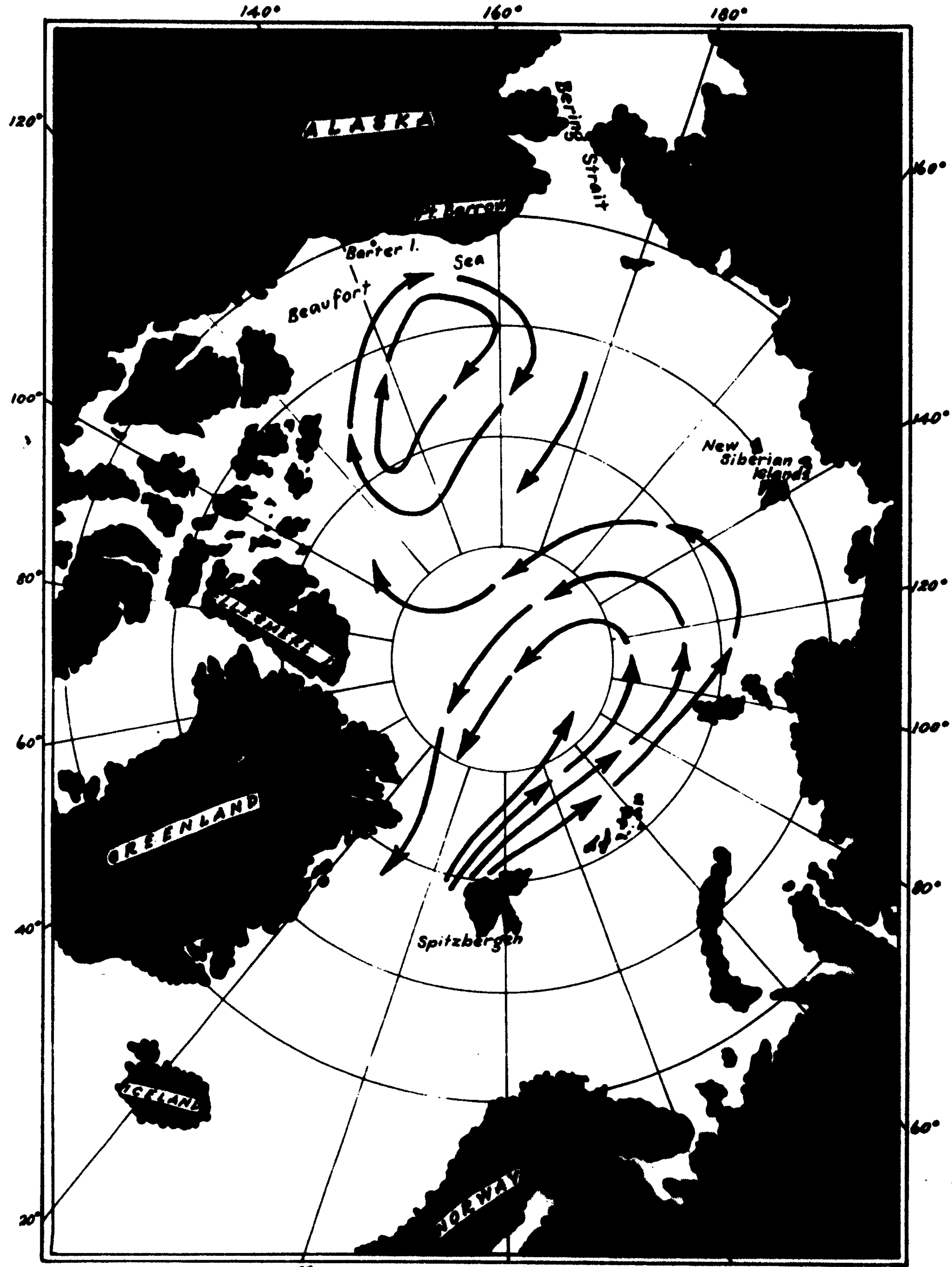


Fig. 12 Subsurface circulation in the North Polar Basin.

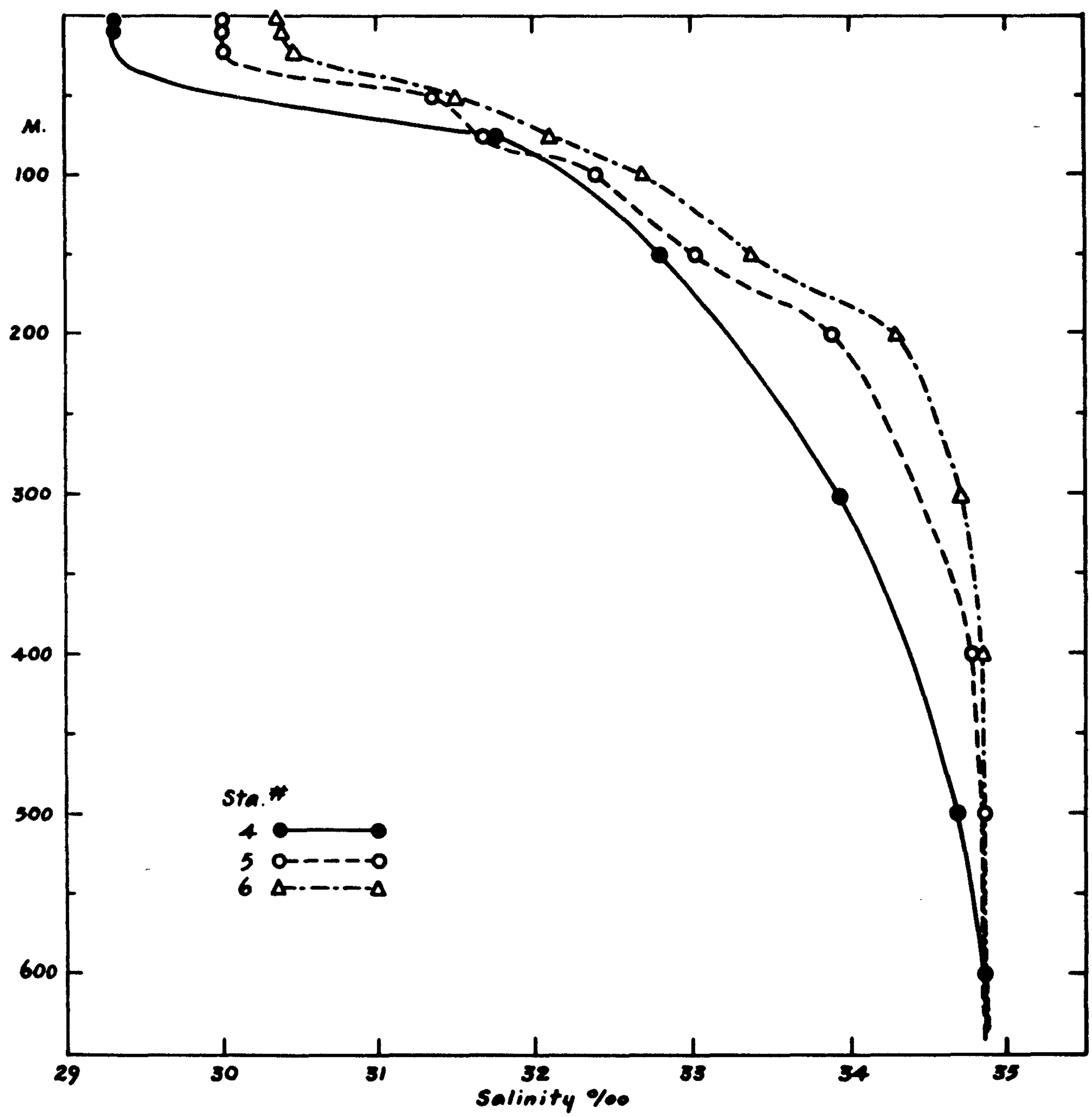


Fig. 13 Salinity-depth curves for SKIJUMP stations.

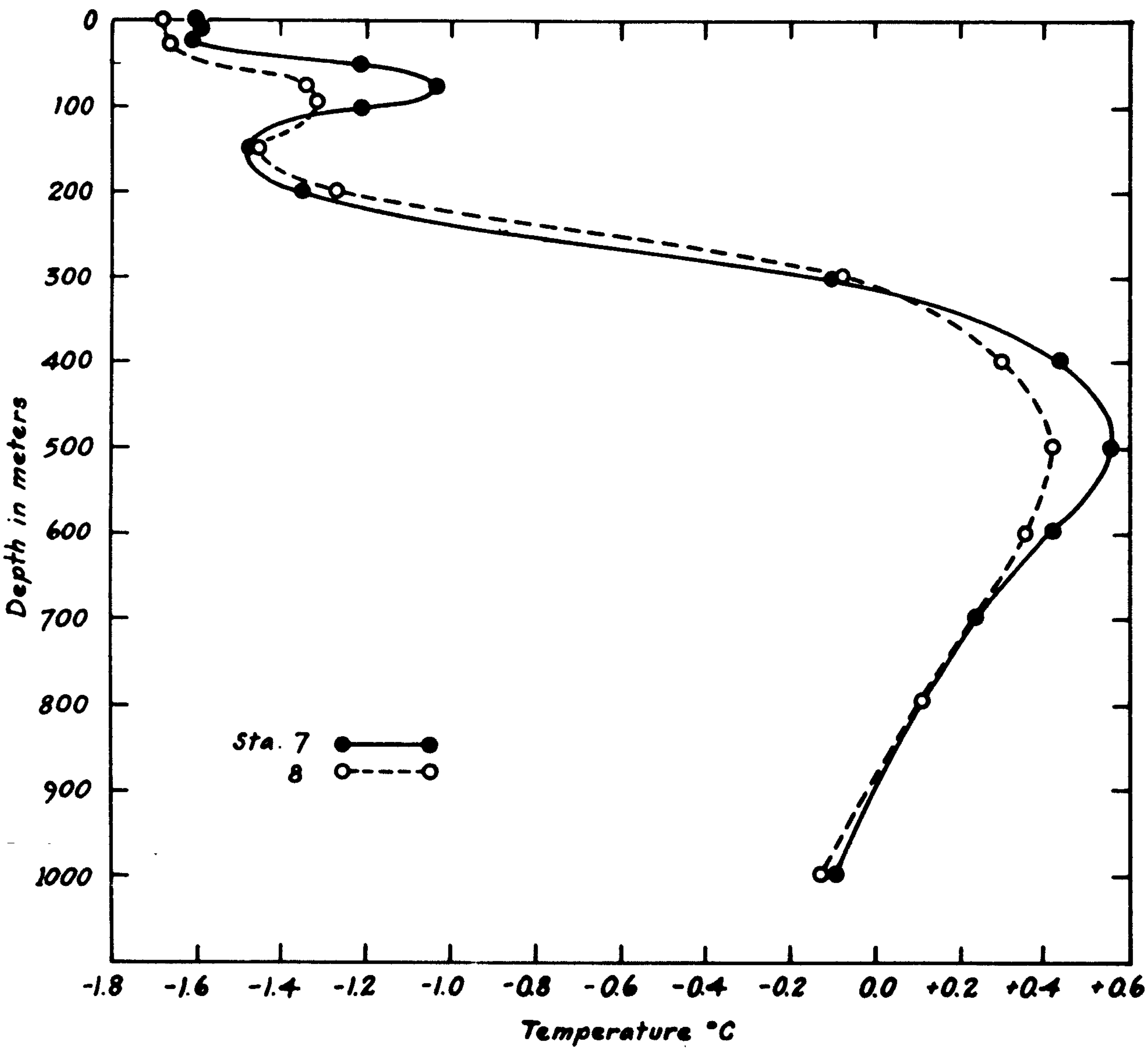


Fig. 14 Two temperature curves showing remnants of a summer thermocline (75 - 150 m.)

No such gradient was found on station 3 which was on the shelf in 171 m. of water, perhaps because vertical mixing takes place to a greater extent on the shelf, and water from the Bering Strait may influence the upper layers in that area.

Below are tabulated the temperatures at the top and bottom of these negative gradients together with the differences between them:

Station	Temperature at top of gradient	Temperature at bottom of gradient	Difference
1	-0.92	-1.51	.59*
2	-1.21	-1.49	.28
3		no gradient	
4	-1.15	-1.46	.31
5	-1.34	-1.49	.15
6	-1.31	-1.45	.14
7	-1.03	-1.48	.45
8	-1.31	-1.45	.14

* Possibly false

The slightly warmer water is apparently carried by the eddy into areas which are covered with ice even in mid-summer. The large gradient found at station 7 is not surprising when it is considered that apart from station 1 station 7 is the closest station to the southern Beaufort Sea in terms of water transport. The low values at stations 5 and 6 give some justification in elongating the eddy toward the northeast as they might be expected to be higher if the water reached their positions from station 7 by a direct route.

Little information exists as to the velocity of the currents in the Polar Sea and how they affect ice movement. The largest value, 10 cm/sec., was found to the north of Spitzbergen (Sverdrup and Soule, 1933) by dynamic computations. The calculated surface current vector at right angles to stations 4 and 5 and stations 5 and 6 was 4 cm/sec.

Indications that the density currents affect the ice drift are few. Most previous sources attribute ice drift to the effect of winds alone. Certainly "Fram" and "Sedov" drifted against the current from the New Siberian Islands to longitude 40°E, but the current values in that region are not known.

"Fram's" drift was slower than "Sedov's" possibly because "Sedov's" more northerly drift was less against the current but

possibly because of stronger winds. Sverdrup (1950) has pointed out, however, that both "Fram" and "Sedov" drifted more rapidly when they approached the Greenland-Spitzbergen channel, evidently not due to wind alone.

Polar Deep Water

Previous sources, "Fram" in 1893-1896 and "Nautilus" in 1931, have agreed that the minimum temperature in the Polar deep water lies between -0.79° and -0.91°. The colder values are found near Spitzbergen where the deep water flows in, and the warmer toward the easterly end of "Fram's" drift. The minimum was found by Nansen between 2500 and 3000 m. below which depth the water becomes adiabatically warmer.

The minimum temperature found in Skijump stations was -0.52° at 2200 m. on station 4. There are in fact indications that this figure is low, due to misreading or malfunction of the thermometer. The thermometer in question was malfunctional on the next series and was not used subsequently. If we accept the reading of -0.52° we must accept a positive gradient of 0.17° between 2200 and 3000 m., a value considerably over the adiabatic rate.

On this basis it appears that the probable temperature minimum in the Beaufort Sea is about -0.45° at 2300 m. This value is 0.34° higher than any minimum previously recorded. Further, since the adiabatic heating starts at a shallower level than in Nansen's observations it seems likely that Beaufort Sea bottom temperatures are as much as 0.50° warmer than those on the other side of the basin.

There are two possible explanations for this; firstly, that the deep water entering the basin from the Norwegian Sea has been warmer in recent years than it was in Nansen's time and secondly, that there is a submarine ridge, running roughly from Ellesmere to the New Siberian Islands, which separates the deepest water of the Beaufort Sea from that of the remainder of the basin.

In support of the latter hypothesis are the observed temperatures in the deep water. Nansen's nearest deep observation to Spitzbergen shows a temperature of -0.87° at 3000 m. This agrees perfectly with the deep temperatures found on the "Nautilus" expedition which range between -0.82° and -0.91° in the 2000-3000 m. level. This, however, does not prove that changes have not taken place between 1931 and the present.

There is some indication from soundings that give further support to the existence of a ridge. Crary et al., (1952)

found depths of up to 3838 m. in the Beaufort Sea, (74°45'N, 150°55'W). On Skijump station 7 about 300 miles to the north the depth had diminished to 2950 m. Unfortunately no sounding was obtained on station 8 but the depth was in excess of 2100 m. by wire.

The sill depth of the ridge should not exceed 2300 m. the depth of the temperature minimum, below which the water is homogeneous or very nearly so. It is not possible on the basis of present observations to estimate how shallow a ridge could be.

TABLE I

Station 1
April 1, 1951
72°52'N, 156°32'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.64	30.26
10	-1.56	---
20	-1.30	30.10
50	-0.92	30.09
100	-1.51	31.87
200	-1.20	---

Station 2
April 21, 1951
75°45'N, 150°00'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.58	29.72
10	-1.61	29.70
20	-1.60	---
50	-1.52	(29.50)
100	-1.21	31.96
150	-1.49	32.55
200	-1.48	33.53
300	-0.07	34.47
400	0.36	34.77
600	0.37	(34.72)
800	0.10	34.85
999	-0.06	(34.70)
1295	-0.26	---
1594	-0.38	---
2092	-0.42	---

Bottom: 3200 m. (sound)

TABLE I (cont'd.)

Station 3
May 3, 1951
72°36'N, 158°32'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.64	30.78
10	-1.68	30.77
20	-1.68	30.78
50	-1.68	31.83
100	-1.77	32.56
150	-0.38	34.39

Bottom: 171 m. (wire)

Station 4
March 11-12, 1952
76°52'N, 144°19'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.60	29.34
10	---	29.31
25	-1.62	---
50	-1.15	30.03
75	-1.15	31.78
100	-1.25	---
150	-1.46	32.80
200	-1.45	---
300	-0.15	33.95
500	0.52	34.70
600	0.38	34.86
800	0.16	34.92
1300	-0.22	34.90
1700	-0.37	34.94
2200	(-0.52)	34.92
3000	-0.35	34.99

TABLE I (cont'd.)

Station 5
March 12, 1952
76°20'N, 134°00'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.64	30.03
10	---	30.02
25	-1.65	30.03
50	-1.72	31.37
75	-1.63	31.70
100	-1.34	32.40
150	-1.49	33.01
200	-1.07	33.90
400	0.35	34.79
500	0.51	34.85
700	0.14	34.87
1000	---	34.88
1300	-0.20	---
1700	-0.36	34.93
2100	-0.42	34.96

Station 6
March 13, 1952
76°20'N, 123°20'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.64	30.38
10	-1.66	30.41
25	-1.68	30.49
50	-1.61	31.51
75	-1.31	32.11
100	(-1.45)	32.71
150	-1.45	33.40
200	-0.74	34.32
300	0.12	34.71
400	0.39	34.83
500	0.39	34.87
600	0.27	34.87

TABLE I (cont'd.)

Station 7
March 25, 1952
79°36'N, 147°10'W

Depth Meters	Temperature °C	Salinity °/oo
2	-1.60	29.33
10	-1.59	---
25	-1.61	29.31
50	-1.21	30.59
75	-1.03	31.73
100	-1.21	32.20
150	-1.48	32.85
200	-1.35	33.62
300	-0.10	34.46
400	0.44	---
500	0.56	---
600	0.41	34.86
700	0.24	34.87
1000	-0.10	(35.02)
1400	-0.25	34.94
1800	-0.37	---
2300	-0.41	34.96

Bottom: 2950 m. (sound)

Station 8
March 26-27, 1952
82°22'N, 145°20'W

Depth Meters	Temperature °C	Salinity °/oo
3	-1.68	30.44
25	-1.67	(30.60)
51	---	30.34
75	-1.34	31.89
100	-1.31	32.57
150	-1.45	33.00
200	-1.27	33.86
300	-0.09	---
400	0.30	34.79
500	0.43	34.85
600	0.31	---
800	0.11	(34.99)
1000	-0.12	(34.88)
1500	-0.30	---
2000	-0.42	---

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